INTERIM SURVEY REPORT:

RECOMMENDATIONS FOR ERGONOMICS INTERVENTIONS

FOR SHIP REPAIR PROCESSES

at

TODD PACIFIC SHIPYARDS CORPORATION
Seattle, Washington

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SIC CODE:	3731
SURVEY DATE:	April 12-13, 2000
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ABSTRACT

A pre-intervention quantitative risk factor analysis was performed at various shops and locations within Todd Pacific Shipyard, as a method to identify and quantify ergonomic risk factors that workers may be exposed to in the course of their normal work duties. The application of exposure assessment techniques provided a quantitative analysis of the risk factors associated with the individual tasks. Based on these analyses, three ergonomic interventions are suggested for the Todd Pacific Shipyard: 1) an ergonomics training program for all production workers, 2) wheeled, adjustable work stools for shipboard welders, torch cutters, and grinders and 3) an orbital nozzle mount for the water jet blasting process in the dry dock area. Of these interventions, it is expected that the development of the ergonomic training program will have the most effective impact on reducing musculoskeletal injuries, and therefore it is the most strongly recommended change. Detailed descriptions of each intervention are provided including cost benefit analysis where appropriate.

I. INTRODUCTION

IA. BACKGROUND FOR CONTROL TECHNOLOGY STUDIES

The National Institute for Occupational Safety and Health (NIOSH) is the primary Federal agency in occupational safety and health research. Located in the Department of Health and Human Services, it was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct a number of research and education programs separate from the standard setting and enforcement functions carried out by the Occupational Safety and Health Administration (OSHA) in the Department of Labor. An important area of NIOSH research deals with methods for controlling occupational exposures to potential chemical and physical hazards, as well as the engineering aspects of health hazard prevention and control.

Since 1976, NIOSH has conducted a number of assessments of health hazard control technology on the basis of industry, common industrial process, or specific control techniques. Examples of the completed studies include the foundry industry, various chemical manufacturing or processing operations, spray painting, and the recirculation of exhaust air. The objective of each of these studies has been to document and evaluate effective control techniques for potential health hazards in the industry or processes of interest, and to create a more general awareness of the need for or availability of an effective system of hazard control measures.

These studies involve a number of steps or phases. Initially, a series of walk-through surveys is conducted to select plants or processes with effective and potentially transferable control concepts or techniques. Next, in-depth surveys are conducted to determine both the control parameters and the effectiveness of these controls. The reports from these in-depth surveys are then used as a basis for preparing technical reports and journal articles on effective hazard control measures. Ultimately, the information from these research activities builds the data base of publicly available information on hazard control techniques for use by health professionals who are responsible for preventing occupational illness and injury.

IB. BACKGROUND FOR THIS STUDY

The background for this study may be found in EPHB Report No. 229-18a, “Preliminary Survey Report: Pre-Intervention Quantitative Risk Factor Analysis for Ship Repair Processes at Todd Pacific Shipyards Corporation, Seattle, WA” by Hudock et al, 2001.

IC. BACKGROUND FOR THIS SURVEY

Todd Pacific Shipyards Corporation was selected for a number of reasons. It was decided to sample t a variety of yards based on product, processes, and location. Todd Pacific Shipyards Corporation is a private shipyard located in the Northwest corner of Harbor Island, in Elliott Bay, near downtown Seattle, Washington. Todd Pacific Shipyards Corporation currently performs vessel repair and overhaul, but has recently finished new vessel construction projects. This yard is considered to be a medium- to small-size yard. Currently, the primary work at the shipyard is the repair and overhaul of both commercial vessels, such as automobile and passenger ferries for the State of Washington, fishing vessels, and military vessels, such as U.S. Navy fast combat support ships (AOEs). Todd Pacific Shipyards Corporation is a member of the Shipbuilders Council of America.

II. PLANT AND PROCESS DESCRIPTION

IIA. INTRODUCTION

Plant Description: Todd Pacific Shipyards Corporation was founded in its present location near downtown Seattle, Washington, in 1916. Todd Pacific has repaired or converted thousands of vessels since its start and has constructed over 300 new vessels. The 46-acre facility has three dry docks, including the largest floating dry dock in Puget Sound, at 873 feet long by 134 feet wide. Two wharves and five piers provide a total of over 6,000 feet of berthing space for outfitting and repair work. A dual shipway allows for the simultaneous construction of two ships with a maximum length of 550 feet and a maximum beam of 59 feet. If both shipways are combined, a vessel 550 feet in length by 95 feet in beam can be constructed. The yard is serviced by fifteen whirled traveling cranes, having lifting capacities up to 136 metric tons. While several original buildings remain on site, Todd Pacific undertook a major site reorganization and capital improvement plan in the mid-1990s. During this time, the shipyard incorporated modern shipbuilding techniques, as acquired from Ishikawajima-Harimi Heavy Industries of Japan. Shops received new equipment and consolidated or relocated to facilitate new technology and work methods at that time.

Corporate Ties: Todd Pacific Shipyards Corporation is a wholly owned subsidiary of Todd Shipyards Corporation.

Products: Todd Pacific just recently completed the construction of three 490 feet long car ferries for the Washington State Ferry System. The shipyard is currently occupied with the repair and overhaul of factory (fishing) trawlers, containerships, barges, tugs, and ferries. Todd Pacific was recently awarded the contract by the U.S. Navy for all long-term life-cycle maintenance on all Puget Sound homeported fast combat support ships (AOEs). The shipyard is also contracted by the Navy for non-nuclear maintenance for the aircraft carriers USS Vinson, USS Lincoln, and USS Stennis.

Age of Plant: The site of Todd Pacific Shipyards has been functioning as a shipyard since 1916. Most of the facility has been updated or rebuilt since that time, as discussed above.

Number of Employees, etc: The facility employees approximately 1,000 production and administrative employees. Of these, typically about 800 are production workers. Eleven different unions represent workers at Todd Pacific.

IIB. SELECTED PROCESS DESCRIPTIONS

Five specific processes were identified for further analysis. These processes were pipe welding, torch cutting, water jet blasting, grinding, and welding operations. All tasks were observed onboard a vessel undergoing repair. Each of these processes are examined in greater detail below.

IIB1. Pipe Welding Process Onboard Vessel

Numerous pipe connections may be required in any repair task. Pipefitters piece together the piping subassemblies and weld them into place. In the shipboard pipe welding process, the pipefitter must first get into position to weld the pipe together. This may involve working in a confined space, working from an elevated surface, and/or working overhead. Using stick electrodes and welding equipment, the pipe assembly is welded into proper position (Figure 1). After the weld is completed, the pipefitter removes the slag from the weld by knocking the slag off with a hammer (Figure 2). Finally, the pipefitter grinds the weld smooth using a small angle grinder (Figure 3).

Figure 1. Pipefitter getting into position to weld

Figure 2. Pipefitter removing weld slag with hammer

Figure 3. Pipefitter using angle grinder to smooth weld

IIB2. Torch Cutting Process Onboard Vessel

There are many ship repair processes in which torch cutting is used to remove steel decking or bulkheads (Figure 4). At times, individual components scheduled for replacement are located in such confined spaces that it is easier to torch cut an opening either beside, above or below an item in order to remove it from its original location. At other times, the physical dimensions of compartments are slated to change for one reason or another, again calling for the removal of decking or bulkheads.

Figure 4. Torch cutting of steel deck

IIB3. Waterjet Blasting of Vessel in Drydock Process

When a vessel comes in for hull repair work, it may be placed in a drydock to lift the vessel out of the water. Instead of using an abrasive blasting agent within the drydock to remove paint, a high-pressure water cannon is used. This process eliminates the need to recover the abrasive agent. A worker enters the platform of a powered lift truck, which has been moved beside the vessel in the drydock. The worker raises and positions the platform to be near the work area. The worker activates the waterjet and proceeds to remove paint from the work surface.

Figure 5. Worker using waterjet to remove paint from vessel

IIB4. Grinding Onboard Vessel Process

In any ship repair process, grinding is a primary task. Paint must be removed from bulkheads or decks prior to painting; weld beads must be ground flush with the plates or attachments. Grinding surfaces can be vertical or horizontal and at floor level, overhead, or somewhere in between. The worker may be standing, kneeling, squatting, or even laying down to perform the task.

Figure 6. Grinding deck stiffeners for deck replacement

IIB5. Welding Onboard Vessel Process

There are three primary types of welding that occur during ship repair processes: manual stick welding, manual wire welding, and semi-automatic wire welding. Stick welding has already been addressed previously for pipe welding. Semi-automatic welding is performed primarily for long straight welds on horizontal surfaces, such as decks. This type of welding is often flux core arc welding where the wire is continuously fed to the arc and the electrode wire has a flux core center that helps to shield the weld. The machine is positioned on the seam to be welded, activated, and then guided by the operator.

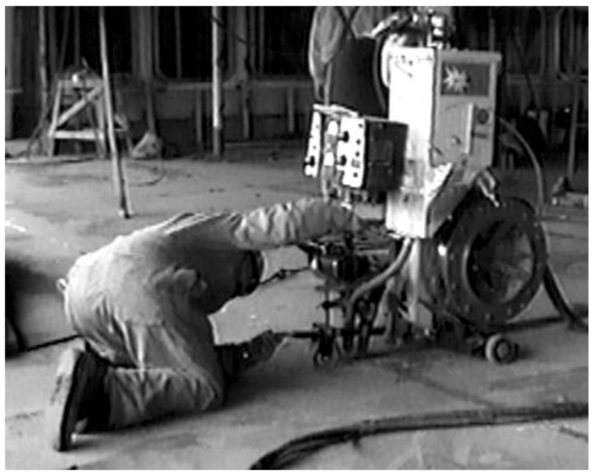

Figure 7. Worker setting up semi-automatic wire-feed welder

Figure 8. Worker operating semi-automatic wire-feed welder

Wire welding is performed for the majority of welding tasks. The wire electrode is continuously fed to the arc and may or may not be shielded by a flux core.

III. ERGONOMIC INTERVENTION COST JUSTIFICATION

The following section has been adapted from the article by Alexander, 1998.

The effectiveness of any ergonomic intervention does not necessarily correlate with the cost of implementing that intervention. The possibility exists for a very effective intervention to be found at a low implementation cost, as well as the possibility of the opposite. The preferred intervention strategy from a business sense is to implement those interventions with the lowest costs and the highest effectiveness. This point can be illustrated by the value/cost matrix as illustrated in Figure 9.

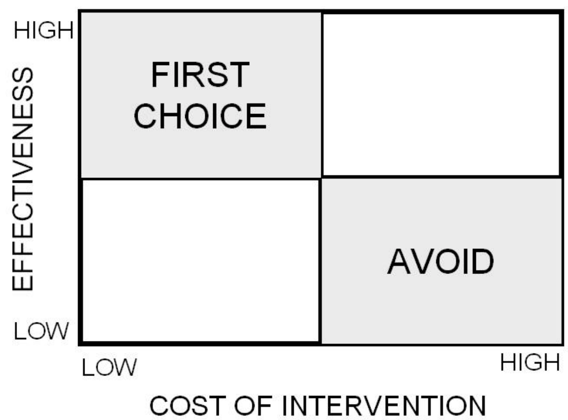

Figure 9: Value Cost Matrix

There are a number of benefits that have been credited to the application of ergonomic interventions in general. The avoidance of current expenses and ongoing losses may include workers compensation costs, overtime pay for replacement workers, increased training and supervisory time, and lost productivity, quality or yields from less skilled workers. Enhanced existing performance may include 1) increased productivity including fewer bottlenecks in production, higher output, fewer missed delivery dates, less overtime, labor reductions, and better line balancing; 2) improved quality including fewer critical operations, more tasks with every operator's control and capacity, and fewer assembly errors; 3) increased operating uptime including faster setups, fewer operating malfunctions, and less operator lag time, and 4) faster maintenance including increased access, faster part replacement, fewer tools needed, more appropriate tools, more power and faster tool speeds. An enhanced quality of worklife may result in less turnover and less employee dissatisfaction. Additional benefits may include fewer traumatic injuries, fewer human errors resulting in lost product or operating incidents, and reduced design and acquisition costs.

In addition to the direct medical costs associated with worker injuries, one must also consider the indirect or hidden costs associated with the primary worker being away from their job. The additional costs of replacement workers include the hiring costs for permanent replacements plus training and other costs, and additional costs for temporary workers who may also have lower work skills than the worker they are replacing. Costs associated with lower productivity include fewer units per hour, lower yields and damage to material or equipment that would not occur with an experienced worker.

Costs associated with lower quality include the number of rejects, the amount of rework, and the timeliness of product delivery. Increased supervision costs include the cost to manage and train a less skilled worker. Training costs to develop and maintain job skills include the amount of lost work time and the cost of the time of trainer.

Many of these indirect costs are difficult to estimate and can vary widely depending on the severity of the injury involved. The ratio of indirect costs to direct costs has also been found by a number of studies to vary between 5:1 to 1:5, depending on industry (Heinrich, 1931, 1959; Levitt et al, 1981; Andreoni, 1986; Leopold and Leonard, 1987; Klen, 1989; Hinze and Applegate, 1991; Oxenburgh, 1991, 1993). As a conservative estimate for its recent ergonomics rule, the State of Washington recently decided upon indirect costs of 75 percent of direct workers' compensation incurred costs (WAC 296-62-051, 2000).

Another aspect of ergonomic interventions that must be considered is the cost benefit analysis. If total costs outweigh all benefits received from implementing the intervention, then from a strictly business sense, the intervention is not worth undertaking. However, from a public health perspective, any feasible intervention that reduces worker discomfort is worthwhile. Regardless, one has to determine the associated start-up costs, recurring costs, and salvage costs of the intervention as well as the time value of money (present worth versus future worth) and the company's Minimum Attractive Rate of Return, the interest rate the company is willing to accept for any project of financial undertaking.

IV. CONTROL TECHNOLOGY

The following section presents various ergonomic interventions that are recommended for implementation in the Todd Pacific Shipyard. These recommendations are based on the risk factor analysis that was performed at Todd in April of 2000 and detailed in a previous NIOSH report (EPHB No. 229-18a).

IVA. ERGONOMICS TRAINING PROGRAM INTERVENTION FOR USE IN ALL PRODUCTION DEPARTMENTS

Five work processes within a ship repair facility were surveyed to determine the presence of risk factors associated with musculoskeletal disorders. The pipe welding task requires workers to combine pipe assemblies, usually in place onboard the vessel. These conditions can result in constrained and awkward postures and unstable footing. Similar conditions also occur for torch cutting, grinding and other welding tasks. Since each repair process to be carried out onboard a vessel is constrained by the physical layout and dimensions of the existing structure, very little can be done in the area of work station redesign or even engineering interventions, in general. It is, however, possible to address concerns raised by improper tool selection and tool usage and poor body positioning. It is suggested that basic ergonomics awareness training be considered for all production workers, emphasizing the areas cited above. While direct changes to the work environment are minimized due to the constraints of ship repair, it is possible to educate the workforce on proper procedures, better work methods and postures to assume while performing the work onboard vessels. The following table lists the key aspects of this recommended intervention, including deliverables.

Table 1: Recommended Ergonomics Training Intervention

• An ergonomics awareness training program will be customized for use at Todd Shipyards by NIOSH personnel and contractors. No commercial versions tailored specifically to the maritime industry are currently available, but general ergonomic training systems that facilitate the set-up of programs are priced from $200-2000. The program should include the following key aspects: • The recognition of workplace risk factors for musculoskeletal disorders and the methods for controlling them. • The identification of signs and symptoms of musculoskeletal disorders and a familiarization with Todd Pacific Shipyard's health care procedures. • Todd Pacific Shipyard's process to address and control risk factors, the employee's role and responsibilities in that process. • The procedure to report risk factors and musculoskeletal disorders within Todd Pacific Shipyard facilities.
• Training will be provided to Todd Pacific safety and production management by NIOSH researchers on the implementation of the ergonomic program throughout the yard, for use especially with the torch cutters, grinders, and welders.
• Todd safety and production management personnel will be expected to utilize the system for a period of at least six months after the date of management training so that the effectiveness of the ergonomic program intervention can be evaluated by NIOSH researchers. This commitment is expected to require approximately two hours per week per individual or selected Todd personnel (2 safety managers expected).
Expected Management Manhour Costs Per Year: $30/hr x 100 x 2 = $6,000
• Selected Todd production personnel will be expected to participate in monthly group training sessions and occasional individual training modules. This commitment is expected to require approximately two hours every 6 months per individual Todd Pacific Shipyard production worker (780 workers in 1999).
Expected Production Manhour Costs Per Year $20/ hr x 4 x 780 = $62,400
• Training materials, including worksheets, information brochures, etc. should be provided to workers for their reference throughout the year.
Expected Material Costs Per Year: $3 x 780 x 2 = $4,680
Expected Total Costs Per Year: $73,080

In identifying benefits of the intervention, one can use the medical and indemnity cost estimates as shown in Table 2 to calculate direct costs.

Table 2: Estimated[1] Shipyard Direct Injury Costs for Musculoskeletal[2] Injuries (medical + indemnity) by Part of Body

[1] Based on analysis of available participating shipyard compensation data from 1996 - 1998
[2] Does not include contusions or fractures

Ankle(s)	$2,390
Arm(s), unspecified	$7,725
Back	$6,996
Elbow(s)	$4,691
Finger(s)	$735
Hand(s)	$6,857
Knee(s)	$7,472
Leg(s), unspecified	$849
Neck	$5,961
Shoulder(s)	$4,960
Wrist(s)	$3,925
Mean Musculoskeletal Injury Cost = $5,523	

From 1996 to 1999, Todd experienced 788 musculoskeletal injuries. The total estimated medical and indemnity cost of these injuries was $4,352,124 based upon the above shipyard industry average costs. If indirect costs are conservatively assumed to be 75% of the direct costs, the total cost of these injuries per year is $1,904,054. It is this amount that can be considered an "avoided cost" and, therefore, a benefit due to the implementation of the intervention. Assuming the ergonomic training intervention eliminates just 1 out of 20 such injuries, the annual savings would be $95,203. A simple benefit to cost ratio would be $95,203/$73,080 or 1.30. Since the benefit to cost ratio is greater than one, it is advantageous and cost-effective to implement the proposed intervention.

IVB. POSSIBLE INTERVENTION FOR THE SHIPBOARD WELDERS, TORCH CUTTERS, AND GRINDERS

Whenever a worker has to kneel or squat for long periods of time to conduct their work, whether it be torch cutting, grinding, or welding, it is suggested that adequate stools or benches be provided which allow the worker to sit to lessen the stress on the knees while still enabling the worker to perform the assigned task at or near floor level without additional strain on the lower back (Figures 10 through 12). Supports are also commercially available that attach to the back of the calf to prevent hyperflexion of the knees during squatting postures (Figure 13).

Figure 10. Worker running automatic welder while on stool

Figure 11. Closeup of worker stool

Figure 12. Short cylinder adjustable tractor seat stool

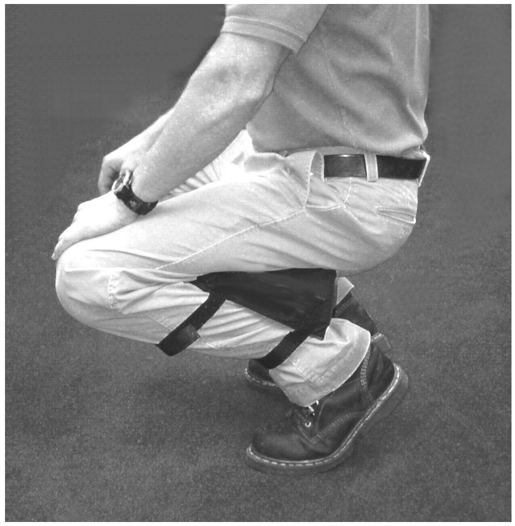

Figure 13. Foam wedge to prevent knee hyperflexion

Suggested approximate work stool characteristics are shown in Table 3. Setup and training time is negligible. Total cost for a crew size supply of stools and knee supports is estimated to be $3,800.

Table 3: Approximate Work Stool/ Knee Support Characteristics

Work Stool (wheeled)	
Capacity	300 pounds
Horizontal Tilt	0 to 45 degrees
Vertical Travel	6 inches (12 inch to 6 inch sitting height)
Price	$150 per stool x 20 (crew size) = $3,000
Knee Support	
Price	$40 pair x 20 (crew size) = $800
Total Price	$3,800

Since Todd injury records include a separate designation for the welding craft, benefits can most easily be calculated based on that department. From 1996 to 1999 Todd experienced eleven back injuries and eight knee injuries to welders that were not due to lifting or falls. The total estimated medical and indemnity cost of these injuries was $144,204, based upon the above shipyard industry average costs by part of body injured. If the nineteen injuries can be said to be due to poor postures and contact stress, the average annual estimate direct cost (over the last four years) for musculoskeletal injuries that may be preventable by measures to relieve these postures and stresses is $36,051. If indirect costs are conservatively assumed to be 75% of the direct costs, the total cost of these injuries per year is $63,089. It is this amount that can be considered an "avoided cost" and, therefore, a benefit due to the implementation of the intervention. Assuming, the intervention fully eliminates such injuries, a simple benefit to cost ratio would be $63,089/$3,800 or 16.6. Since the benefit to cost ratio is greater than one, it is advantageous and cost-effective to implement the proposed intervention. However it is possible that only half of the estimated annual injury cost is saved each year. It is also possible that the weld stools/ knee supports last only 6 months. Assuming that the shipyard has a minimum attractive rate of return of 20 percent for any project cash outlay, one can still calculate a benefit to cost ratio by utilizing the following equation to determine the present worth of an annual savings:

Equation 1: $$PW = AS \times \frac{\left[(1+i)^n - 1\right]}{i \times (1+i)^n}$$

where PW = present worth
AS = annual savings
i = interest rate (ex., 0.20 for 20 percent)
and n = number of years.

Using an annual savings of just $31,545 (half of the estimated annual injury cost) at an interest rate of 20 percent over a half year period, the present worth of the proposed savings would be $13,742. Assuming initial costs of the weld stools/ knee supports are $3,800 and negligible annual costs, the benefit to cost ratio of implementing this intervention is $13,742/$3,800 or 3.62, greater than one, and therefore still economically advantageous.

IVC. POSSIBLE INTERVENTIONS FOR THE WATERJET BLASTING PROCESS

The primary concern with the waterjet blasting process is that workers are required to hold the water cannon in their hands to control and direct the high-pressure water spray. It is suggested that an orbital nozzle mount, similar to those found on fire engines, be fixed to the railing of the platform of the lift. The water spray can still be directed to the hull or other work surface with a high degree of flexibility while the nozzle mount removes the worker from the strain of holding the water cannon directly. The estimated cost of installing such an orbital nozzle mount is provided below in Table 4.

Table 4: Cost Summary of Orbital Nozzle Mount Intervention

Cost of Raw Materials (mounting bracket, other hardware)	\$100
Cost of Orbital Nozzle	\$2,500
Cost of Labor	\$400
Total Cost	\$4,000 x 2 (crew size) = \$8,000

From 1996 to 1999 Todd experienced six back, two arm (unspecified), and one elbow musculoskeletal injuries to drydock riggers (water blaster craft designation) that were not due to being struck by objects or falling. The total estimated medical and indemnity cost of these injuries was \$77,859, based upon the above shipyard industry average costs by part of body injured. If the nine injuries can be said to be due to the operation of the water blasters, the average annual estimate direct cost (over the last four years) for musculoskeletal injuries that may be preventable by the orbital nozzle intervention is \$19,465. If indirect costs are conservatively assumed to be 75% of the direct costs, the total cost of these injuries per year is \$34,063. It is this amount that can be considered an "avoided cost" and, therefore, a benefit due to the implementation of the intervention. Assuming, the intervention fully eliminates such injuries, a simple benefit to cost ratio would be \$34,063/\$8,000 or 4.26. Since the benefit to cost ratio is greater than one, it is advantageous and cost-effective to implement the proposed intervention. However it is possible that only half of the estimated annual injury cost is saved each year. It is also possible that the orbital nozzles last two years. Assuming that the shipyard has a minimum attractive rate of return of 20 percent for any project cash outlay, one can still calculate a benefit to cost ratio by utilizing the following equation to determine the present worth of an annual savings:

Equation 1: $$PW = AS \times \frac{\left[(1+i)^n - 1\right]}{i \times (1+i)^n}$$

where PW = present worth
AS = annual savings
i = interest rate (ex., 0.20 for 20 percent)
and n = number of years.

Using an annual savings of just $17,032 (half of the estimated annual injury cost) at an interest rate of 20 percent over a two year period, the present worth of the proposed savings would be $26,021. Assuming initial costs of the orbital nozzles are $8,000 and negligible annual costs, the benefit to cost ratio of implementing this intervention is $26,021/$8,000 or 3.25, greater than one, and therefore still economically advantageous.

V. CONCLUSIONS AND RECOMMENDATIONS

Five distinct repair processes were examined at Todd Pacific Shipyard facilities to quantify the musculoskeletal risk factors associated with these processes. The processes included: pipe welding, torch cutting, waterjet blasting, grinding, and welding. Based on ergonomic task analyses, three ergonomic interventions are suggested for the Todd Pacific Shipyard: 1) an ergonomics training program for use in all production departments, 2) wheeled, adjustable work stools for shipboard welders, torch cutters, and grinders, and 3) an orbital nozzle mount for the water jet blasting process in the dry dock area. Since ship repair work greatly differs from ship construction processes, particularly with respect to the ability to change the work environment, it is expected that the development of the ergonomic training program will have the most effective impact on reducing musculoskeletal injuries, and therefore it is the most strongly recommended change.

The implementation of engineered ergonomic interventions has been found to reduce the amount and severity of musculoskeletal disorders within the working population in various industries. Therefore, it is suggested that the other suggested ergonomic interventions may also be implemented at Todd Pacific shipyard to minimize hazards in the identified job tasks, if feasible.

Each of the interventions proposed in this document are to be considered preliminary concepts. Full engineering analyses by the participating shipyard are expected prior to the implementation of any particular suggested intervention concept to determine feasibility, both financially and engineering, as well as to identify potential safety considerations.

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